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J Main and
G I Sangster

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A Study of Bottom Trawling Gear on both Sand and Hard Ground

J Main and G I Sangster

Marine Laboratory Aberdeen

Introduction

Two important recent developments have made it possible directly to observe any chosen parts of a fishing gear while being towed at speeds up to 4.5 knots. A specially developed wet towed vehicle TUVII (Plate I), carrying a pilot and observer wearing conventional self-contained underwater breathing apparatus, gives the divers shetler, so allowing observation periods limited only by the necessity for avoiding decompression. A hand-held sensitive underwater television camera fitted with an RCA Sitcon tube allows the diver to make video tape recordings of the components of special interest (Main & Sangster, 1976, 1978a, 1978b; Wardle & Priestley 1976.)

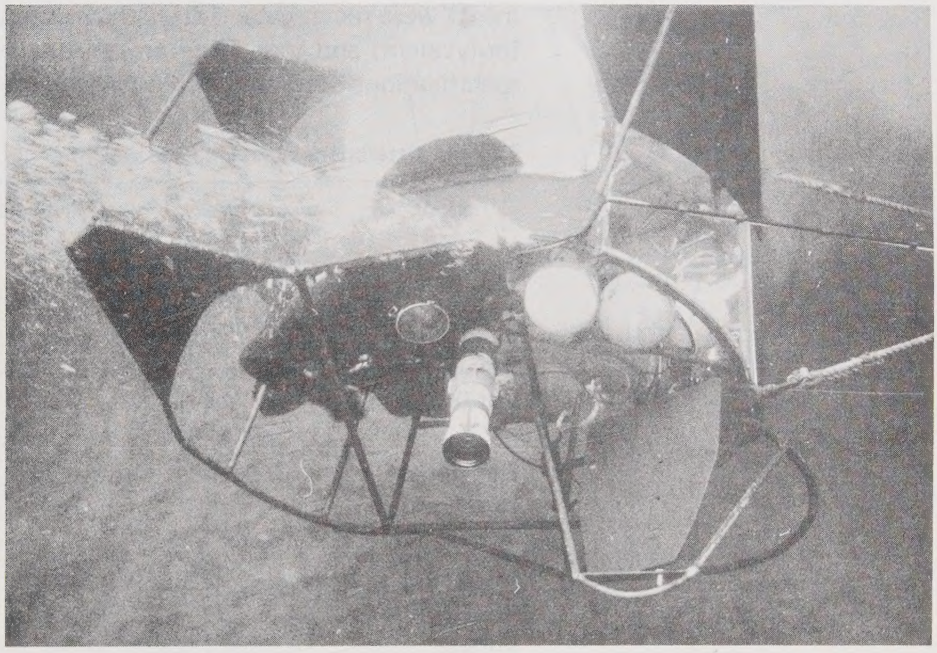


Plate I. The Towed Underwater Vehicle (TUVII) used by the diving scientists during the gear performance experiments.

These new techniques, together with instrumentation and direct measurements of the dimensions of the gear, afford the scientist a unique view of the behaviour of the whole gear and a closer and continuous view of any chosen component of particular interest. They were used to observe and analyse the behaviour of a number of commercial and experimental types of trawl boards and ground gears on rough and smooth fishing grounds.

Trawl boards must be effective in spreading the sweeps and wings of the net as well as surviving collisions with rocks and boulders. They are also known to generate turbulence and sand clouds along either side of the gear. Previous observations by free-swimming divers, (Main & Sangster, 1978b), from a one atmosphere towed submersible (Korotkow & Martyschewski, 1977), or from a towed (wet) sledge (Jansson & Nilsson, 1977), have illustrated these points, but they have been insufficiently detailed to allow a full description of the trawl board behaviour on both smooth sand and hard ground. The function of the ground gear of a trawl is to protect the fishing line without deterring fish from rising into the mouth of the trawl. Careful observations of commercial ground gears could show how to achieve this whilst preserving economy in design.

Results from this type of study give a clearer understanding of how existing gears catch fish, and help us to develop ideas on design and selection of fishing gear components and on the selectivity of fishing gears for particular species of fish.

Material and Methods

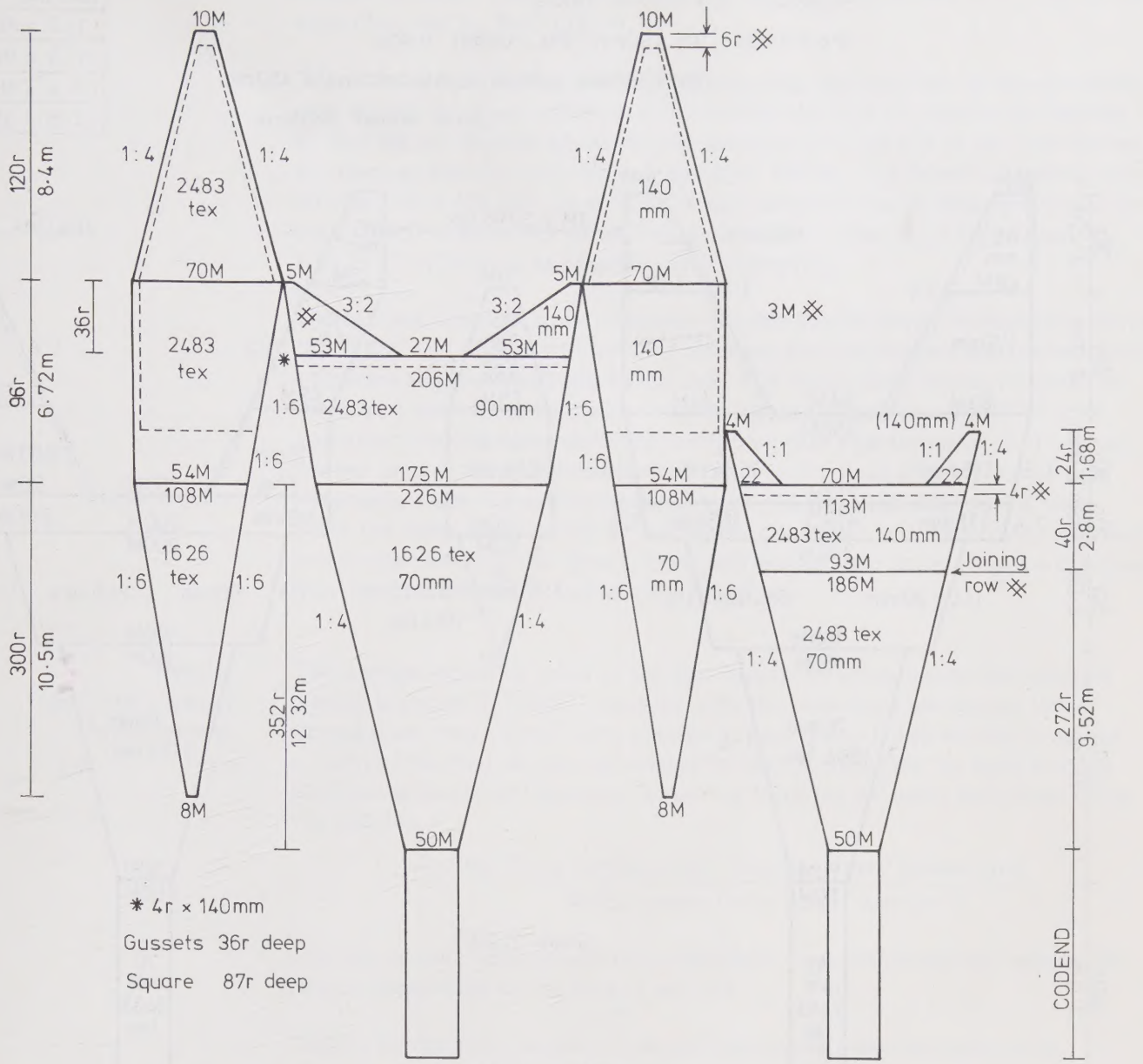
Experiments were carried out from the fisheries research vessel "Mara", (200 hp, 22 m) arranged as a side trawler. A detailed echo sounder and Decca plotter survey was made to find a test area which would allow fishing from smooth sand to hard rocky ground. The area chosen, approximately 3½ miles (5.6 km) ENE of Lossiemouth (57° 41'N, 03°03'W), allowed a fourteen minute tow at 1.54 m s^{-1} (3 knots). This covered rough ground with boulders of a variety of sizes up to 2 metres in height, with clear smooth sand at each end. Water depth ranged from 24 to 28 m (12 to 14 fm).

The two nets compared were the new Aberdeen 4-panel "Lossie J" trawl, designed to cope with rough ground (Corrigall & Watson, 1977), and the Boris 'Mystic', an accepted commercial net used by many Scottish fishermen. Both nets and their rigging specifications are described in detail in Figures 1 and 2. The four types of trawl board used during the performance experiments were rectangular flat, rectangular cambered, oval cambered slotted (polyvalent) and Vee. Their dimensions are shown in Table I and their design specifications described in the FAO Fishing Manual (Anon., 1974).

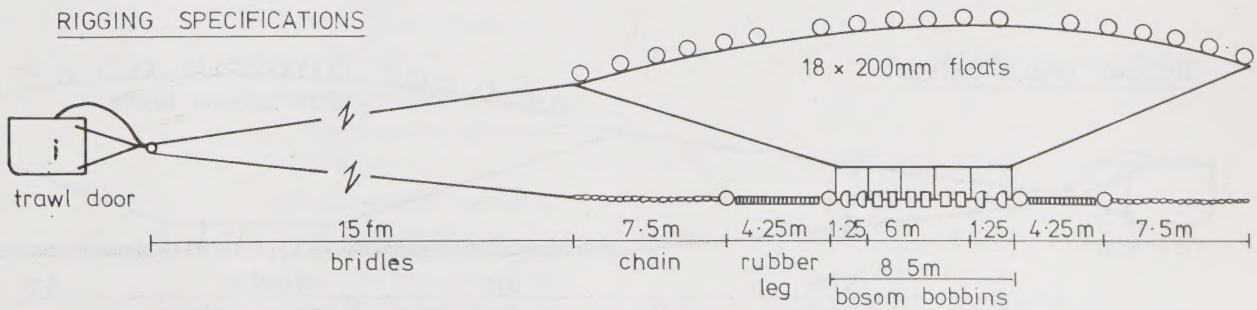
Table I. Otterboard type, area and weight

Door	Size	Projected area		Wt in air		Wt in sea water	
	Overall length and Overall breadth	ft^2	m^2	lb	kg	lb	kg
Rectangular Flat (Wooden)	5ft 8in x 3ft 3in or 1.7m x 0.99m	17.8	1.6	225	102	115	52
Rectangular Cambered (Steel)	5ft 8in x 2ft 11in or 1.7m x 0.89m	16.5	1.5	347	158	249	113
Polyvalent (Oval Cambered Slotted) (Steel)	5ft 7in x 3ft 5in or 1.7m x 1.05m	19.0	1.7	476	216	356	162
Rectangular Vee (Steel)	5ft 10in x 3ft 4in or 1.7m x 1.0m	19.0	1.7	344	156	320	145

Both the port and starboard towing warp tensions were monitored on board ship, using two calibrated 0.4545 kg (4.5 ton maximum reading) tension meters manufactured by Transducers (CEL) Ltd, Reading, England. These meters are arranged to take up the full tension of the warps as they leave the stern of the fishing vessel, and the tension was continuously recorded whilst towing over the test area. Owing to the vibrations of the towing warps from the fishing gear crossing the hard ground, it was possible to use only impact readings greater than 50 kg (1 cwt) from the tension meter traces. A divergence meter continuously recorded warp angles at the ship's stern, so that the changes in spread between the otterboards could be calculated when the net encountered fasteners. More recently a DAFS Marine Laboratory Mark 5 spread meter and its transponder unit were attached to the warps (on 1 m steel strops) 1 m in front of each board, in order to evaluate the spread measurements made with the divergence meter. The calibrated instrument



RIGGING SPECIFICATIONS



Bosom - 6m rubber wheels (350mm) Rubber Leg - 9m rubber disc (90mm)

All on 12mm Drag Alloy Chain

Figure 1. Net diagram and rigging specification of the Aberdeen 4-panel "Lossie J" trawl used in the experiment.

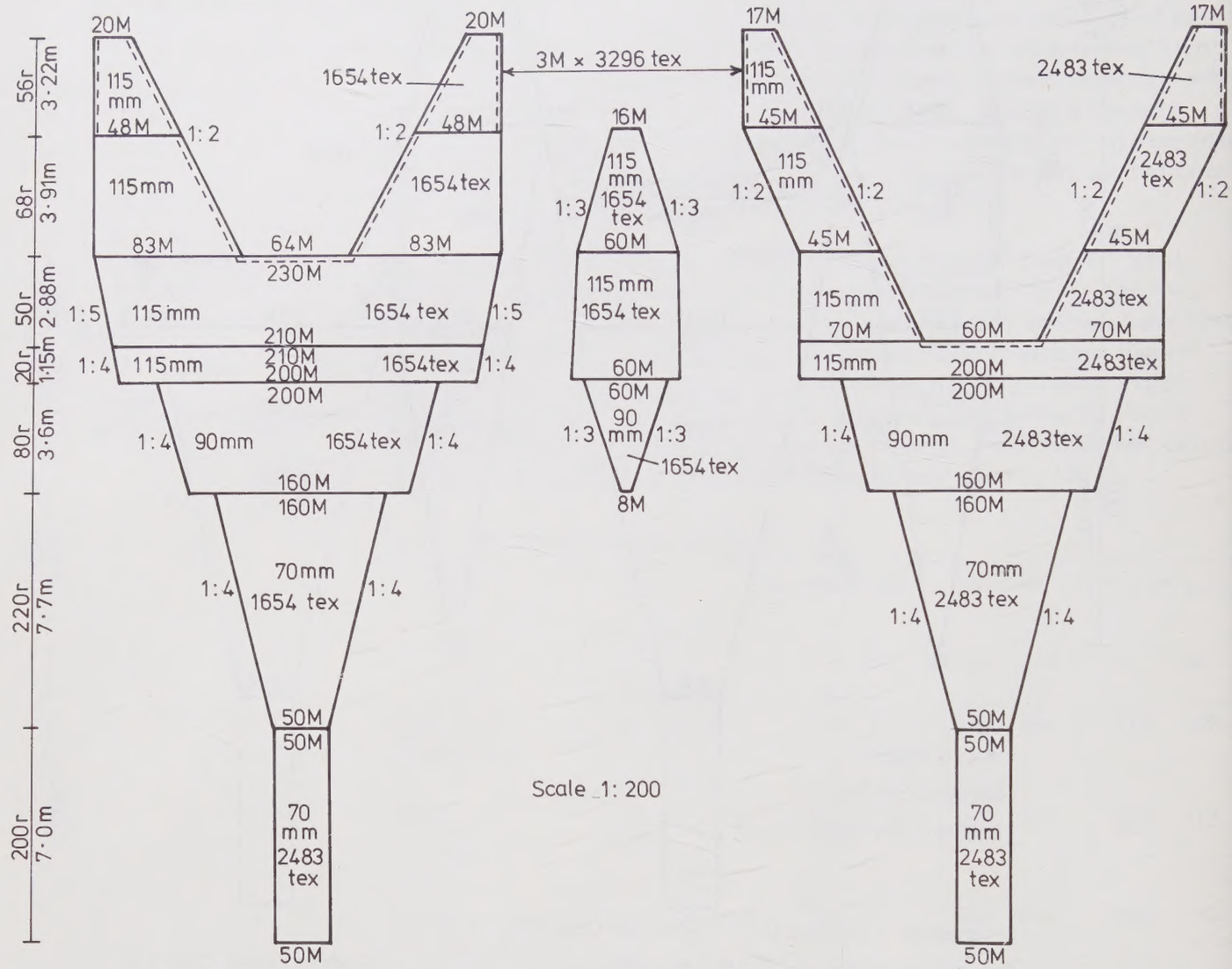
BORIS MYSTIC BOBBIN TRAWL (150 - 500 hp)

Flotation - 20 x 200mm floats

Groundrope - 9m x 90mm dia rubber discs

6m x 350mm rubber bunt bobbins + 450mm rubber wheel bobbins

BAITING RATES
1 : 2 = All bars
1 : 3 = 1N4B
1 : 4 = 1N2B
1 : 5 = 3N4B

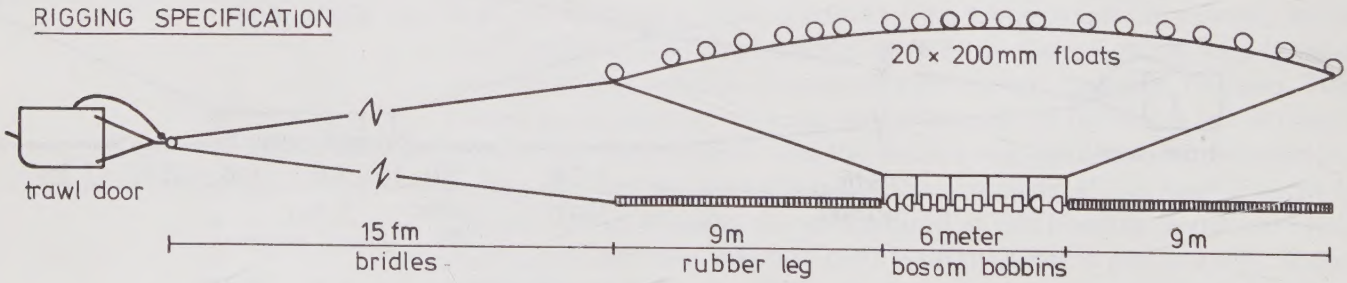


Headline - 18·9m (1·0 + 7·1 + 1·0) x 16mm pre-stretched terylene

Fishing lines - 25m (1 + 10 + 3 + 10 + 1) x 20mm polyethene + 24mm polyethene

Groundrope - 24m (9 + 6 + 9) Winglines - 7m x 16mm pre-stretched terylene

RIGGING SPECIFICATION



Bosom - 6m rubber wheels (350mm) Rubber Leg - 9m rubber disc (90mm)

All on 12mm Drag Alloy Chain

Figure 2. Net diagram and rigging specification of the "Boris Mystic" trawl used in the experiment.

results from both meters, when compared by this method, were found to be reliable to within 1 m. The accuracies of the instruments and their calibrations were discussed by Reid (1976).

"Mara" towed the fishing gear and manoeuvred into position for the proposed tow, so that the diver controlling the TUVII had time to position the vehicle so that the cameraman could observe the boards or net just as the gear started to pass over the test area (Main & Sangster, 1978a). The length of towing warp aft was 137 m (75 fm), an acceptable gear geometry being obtained at a water depth of 25 to 28 m (12 to 14 fm), and the ship speed was kept as near 1.54 m s^{-1} (3 knots) as possible using a speed log.

The net was observed from a position outside the left wing, immediately above and to the rear of the bunt bobbins, whereas each otterboard was viewed from a position slightly ahead and to the side. The direct observations recorded on video tape from the diver-held television camera, together with the remote instrument recordings, monitored the fishing gear's performance as it crossed the test area. A clock inserted on the video-tape frames allowed the picture information and the tension readings to be synchronised and related later. From the video tapes produced the typical behaviour and performance of each board when passing over obstructions was assessed and composite line drawings from selected television frames were made.

Results

Trawl board spread measurements

The average spread for each of the four boards on smooth sand and on hard ground is shown in Table II together with the calculated percentage loss of spread when they moved from smooth to hard ground. The spreading ability of each of the four boards was related to their surface area for both smooth and hard ground and figures for spreading force per m^2 were calculated using the formula

$$\frac{\text{Average Warp Tension (kg) x Average Board Spread (m)}}{\text{Warp Length (m) x Board Area } (m^2).}$$

The best spread measurements were obtained from the cambered rectangular boards irrespective of the type of sea bed.

Table II. Average board spread on sand and rough ground, percentage reduction in spreading ability and spreading force per unit area. For board dimensions see Table I

	Standard rectangular	Polyvalent board	Cambered rectangular	Vee board
Average board spread on sand	17.5m	20.1m	20.7m	17.4m
Average board spread on rough ground	16.8m	15.1m	17.8m	15.1m
Percentage loss in spread from sand to hard ground ground	5.0%	24.8%	14.0%	13.2%
Spreading force per m^2 on smooth sand (kg m^{-2})	60.28	55.66	65.47	59.02
Spreading force per m^2 on rough ground (kg m^{-2})	58.40	46.10	57.16	52.64

Trawl board visual observations

Rectangular flat

These flat wooden boards were very stable on the smooth ground, and could have good contact with the sea bed along the whole length of the keel. On smooth sand, the sand particles were sucked into the trailing face of the board, a substantial cloud billowed from the edges and completely obliterated the backstrops and sweeps, (Plate II). On the hard ground, the sand cloud was reduced and larger particles of debris were drawn into the turbulent region behind the board. This board rose over boulders reasonably well while remaining stable. The board struck rocks very hard with the leading vertical edge, then tilted forward, sliding up on the leading edge before rising clear of the obstruction (Fig. 3); larger rocks caused the board to hinge on the leading vertical edge and swing in a horizontal plane, (Fig. 4). The board nearly always landed toe down after lifting over an obstruction (Figs. 3, 4). Contact between the rear half of the board and a boulder or rock appeared to have little or no effect on either the board attitude or the recorded towing tension. Their attitude whilst crossing deep sand ridges (0.5 m) remained similar to that on the smooth sand, with the keel cutting about 15 cm through the ridge crests, without adding any measurable tension on the recording meters. The average spread between the boards when crossing smooth sand was 17.8 m, but decreased to 16.8 m on the hard ground. The minimum spread recorded on the hard ground was 14.8 m (Table II).

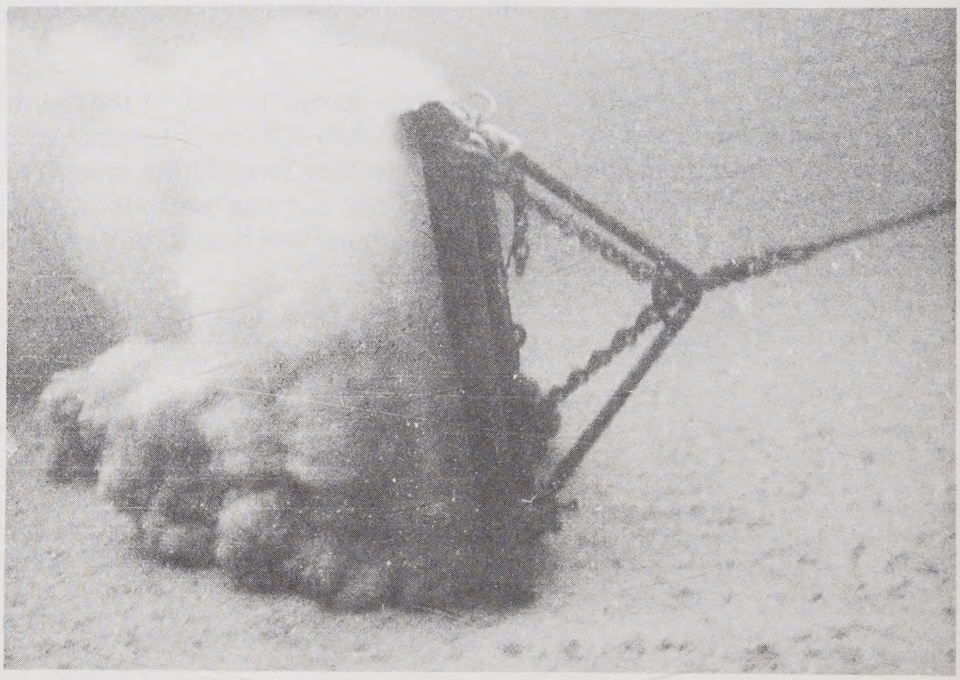


Plate II. Rectangular flat board showing the large sand cloud filling the rear of the board.

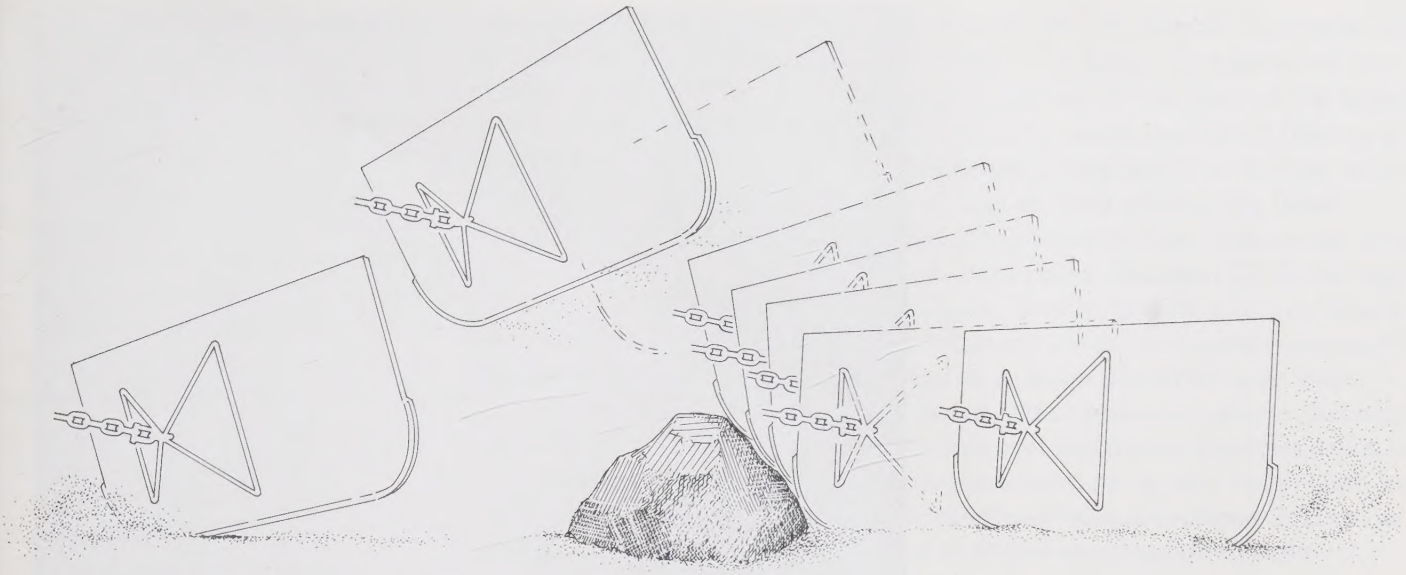


Figure 3. Behaviour of the rectangular flat board on hard ground.

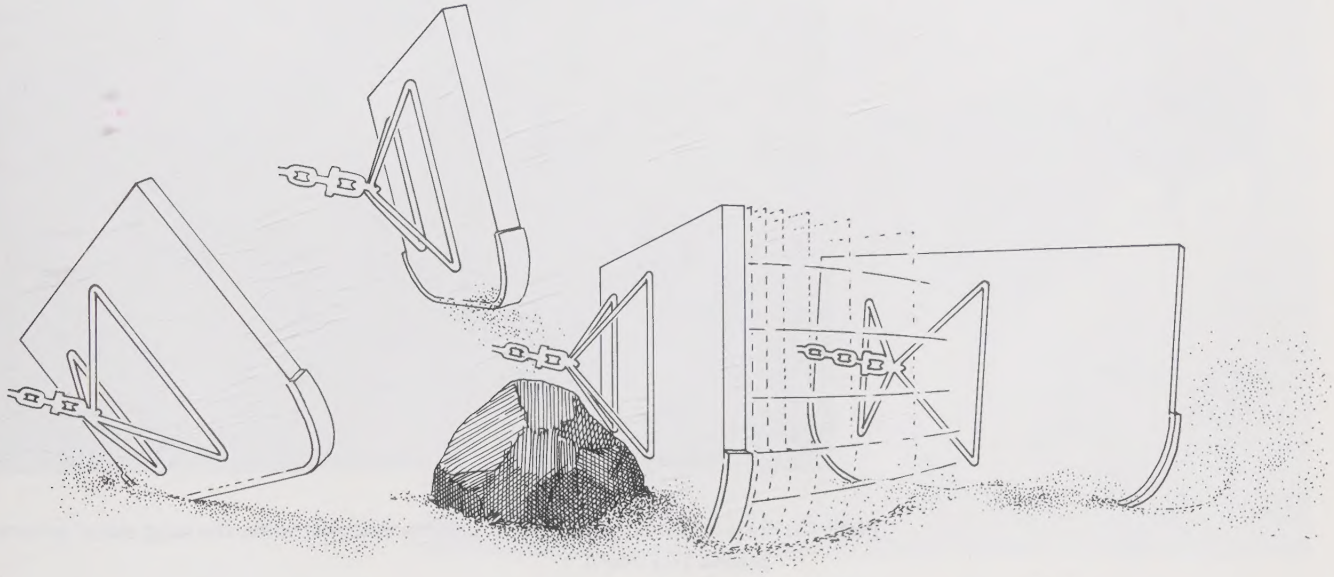


Figure 4. Rectangular flat board striking an obstruction and demonstrating the hinging behaviour on the leading edge.

Polyvalent (oval cambered slotted)

These steel boards were seen to be more mobile and dynamic, being stable on the smooth sand but bouncing vigorously on sand ridges. A sand cloud was generated similar to that by the rectangular flat board (Plate III) and reduced in the same way on hard ground. Contact with the sea bed took place only on a small area of the curved keel on smooth sand. On rough ground these boards rode easily over large boulders up to 2 m high because of the curved shape of the lower leading edge of the board. The board slid up the boulder on the leading curved edge, then tilted with its top edge inwards, swivelling about its longitudinal axis, and then back to a vertical position before striking the sea bed on its keel in the upright position (Fig. 5). When the fishing net momentarily came fast this board was twice seen to rise 2-3 m from the sea bed and move inwards towards the opposite board. It settled on the sea bed again with only 7.8 m between the doors. When the obstruction was cleared by the net, the boards returned to their original 15.4 m spread in 35 seconds. The polyvalent boards had an average spread of 20.1 m on smooth sand which was decreased to 15.1 m on the rough ground (Table II).

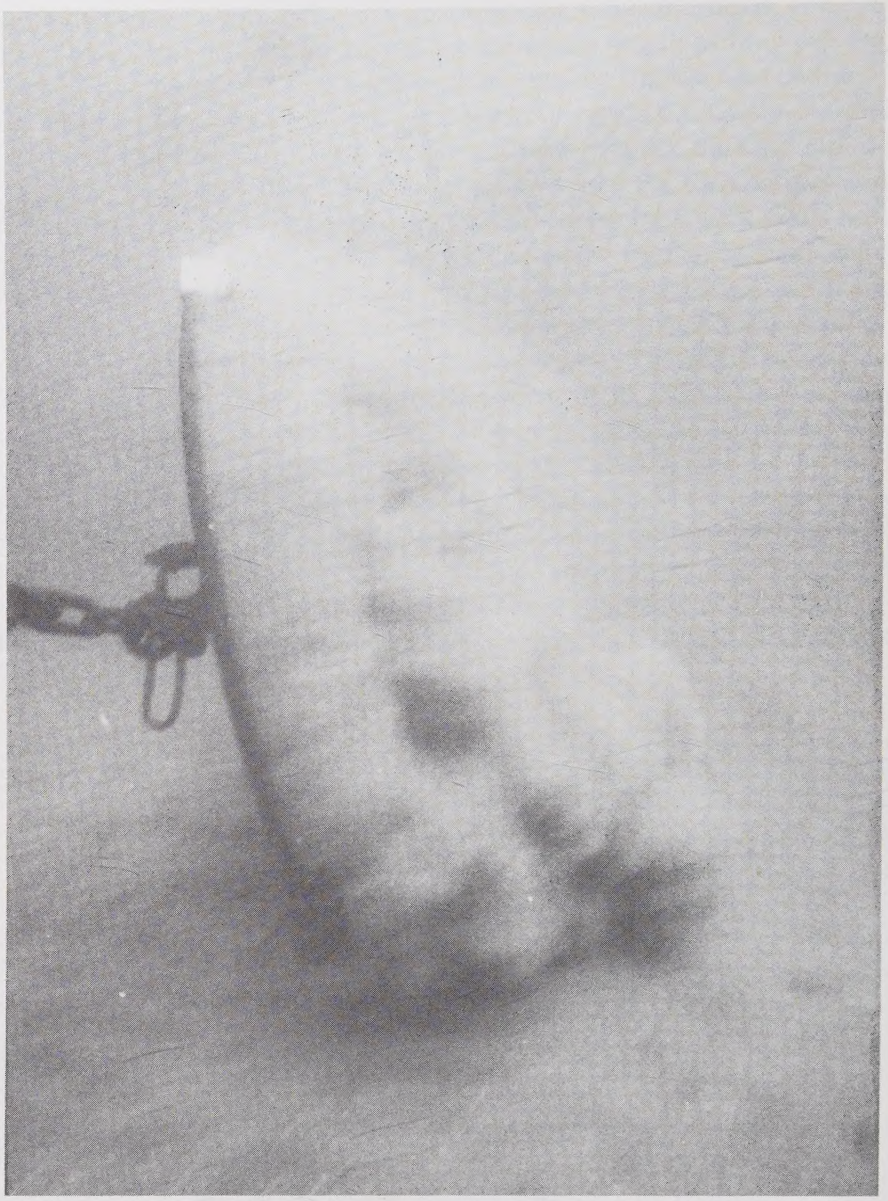


Plate III. Polyvalent board on sandy bottom demonstrating the sand cloud generated behind this board.

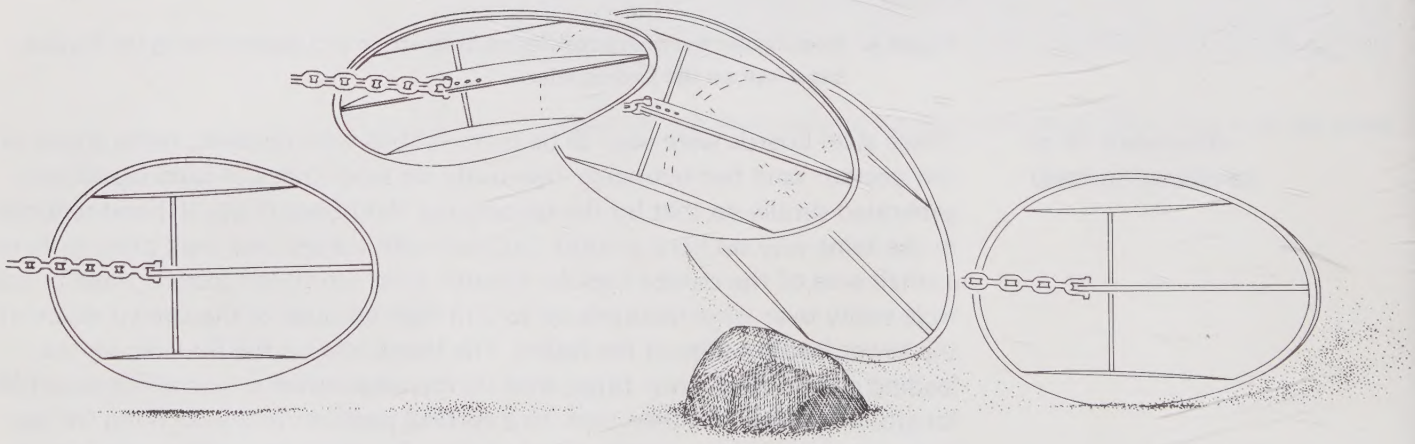


Figure 5. Polyvalent board rising and swivelling as it clears the obstruction.

Rectangular cambered

These steel boards are very stable on smooth ground, and can have good contact with the sea bed along their keel length. The sand cloud generated, in contrast to that of the other three boards, did not fill the back of the board; sand and debris lifted backwards only along the lower quarter of the board near the keel, and rose only to the full height of the board at the rear edge (Plate IV). On deep sand ridges (0.5 m) and on hard ground this board remained stable and upright. It tended to glide rather than bounce over small rocks (20-25 cm high), and could push small rocks (less than 20-25 cm high) out of its path without altering its attitude. Smaller boulders firmly fixed to the sea bed caused the lower edge to move outwards, the board tilting gently about a median longitudinal horizontal axis. When presented with large boulders (more than 1 m high), this board had a behaviour pattern different from that of the standard rectangular board. It slid up the boulders on its keel rather than on its leading edge and tended to land on its keel rather than its toe (Fig. 6). The spread between the cambered boards averaged 20.7 m on smooth sand but was reduced to 17.8 m on the rough ground (Table II).

Plate IV. Cambered rectangular board, showing the low sand cloud generated immediately behind the board.

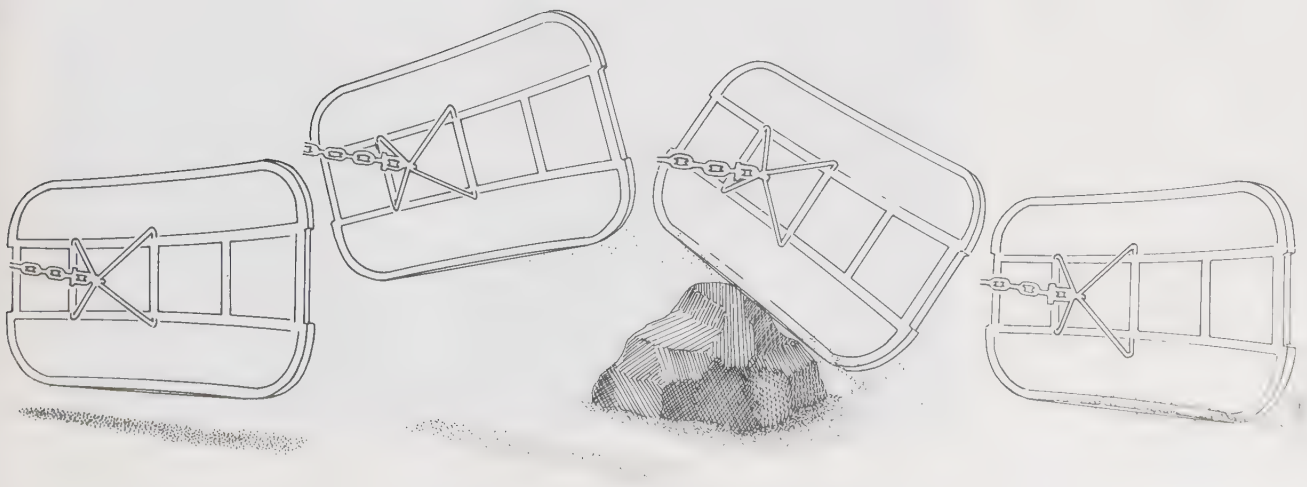


Figure 6. Cambered rectangular board clearing an obstruction.

Rectangular Vee

Vee boards, like the flat and polyvalent boards, were stable on smooth sand, and a large sand cloud was generated filling the back of the board (Plate V). The keel of the Vee board remained in contact with all types of sea bed. When encountering an obstruction it swivelled on its median horizontal axis, ie it hinged on the triangle bracket, and the lower half of the board skimmed in the horizontal plane over the obstruction (Fig. 7). When the lower half of the board was horizontal, the upper half was still inclined upwards and the water flow pressed the board to an upright position again before it retouched the sea bed. The steel Vee board was stable on hard ground, but unlike the cambered board it was more easily swivelled and did not push rocks out of its path. On sand ridges in line with the keel of the board, the Vee board swivelled on its towing bracket (Fig. 7) as it crossed the ridge crests. When the ridges were at 90^{o} to the keel, the board pitched and yawed as it followed the contour of the ridge. The average spread between the Vee boards was 17.4 m on smooth sand, but was reduced to 15.1 m on the rough ground (Table II).

Plate V. Vee board on sand, showing the sand cloud filling the rear of the board.

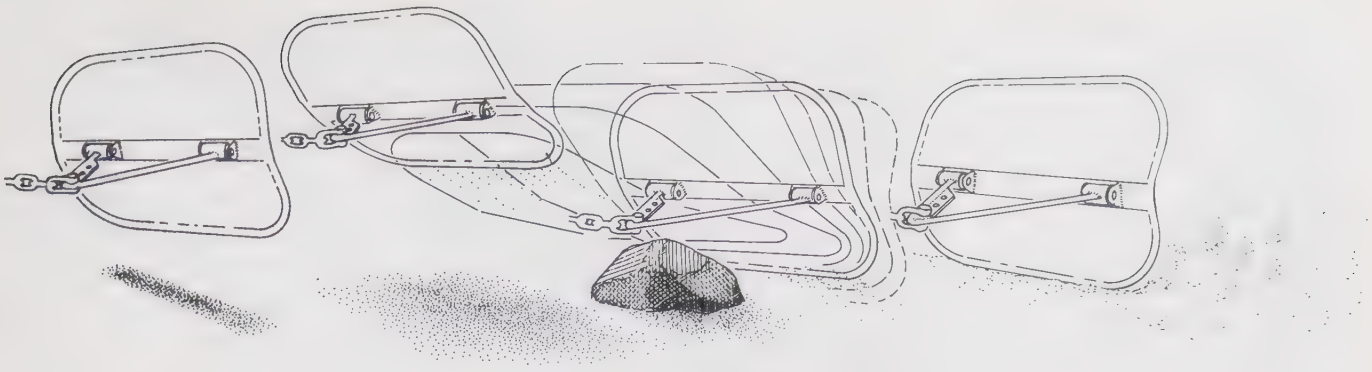


Figure 7. Vee board clearing an obstruction by hinging on its towing bracket, before returning to an upright position

Tension records and board behaviour

It was found that the measured increases in warp tension could be related to the degree of reaction of the board with the obstruction observed on the television record. Table III gives some selected results of each of the four board types, showing the recorded warp tension of each board, the size of obstruction hit, the type of reaction described by the board attitude and impact point and the increase in tension.

Table III. Some selected results of trawl board behaviour and warp tension on smooth sand and rough ground showing the increases in tension on impact with various sizes of obstruction

Board type	Towing speed (knots)	Mean towing tension on smooth sand (kg)	Mean warp tension on rough ground before impact (kg)	Actual increase in warp tension on impact (kg)	Height of obstruction (cm)	Trawl board attitude	Point of impact
Rectangular flat	3.0	755					
	3.0		762	243	30	rode over	toe
	3.0		762	330	45	rode over	toe
	3.0		762	101	20	rode over	toe
	3.0		762	152	20	rode over	middle
	3.0		762	203	20	rode over	middle
	3.0		762	182	30	rode over	middle
	2.9		762	1117	20	dug out	toe
	2.85		762	457	45	rode over	toe
	3.1		762	558	20	dug out	toe
	3.1		762	208	20	rode over	toe
	2.9		762	263	20	pushed	toe
Polyvalent	3.0	645					
	2.9		660	508	30	rode over	middle
	2.9		660	254	45	rode over	middle
	2.9		660	457	45	rode over	middle
	2.9		660	101	20	rode over	middle
	2.9		660	203	30	rode over	middle
	2.9		660	254	30	rode over	middle
	2.9		711	152	20	rode over	middle
	2.9		762	558	180	rode over	toe
	2.9		762	304	20	pushed	toe
	2.9		762	254	60	rode over	middle
	2.9		711	101	45	rode over	middle
	2.9		711	101	60	rode over	middle
	2.9		711	1422	60	rode over	middle
	2.9		711	914	60	rode over	toe
	2.8		762	152	30	rode over	toe
	2.8		762	609	60	pushed	toe
	2.8		762	152	60	rode over	middle
Cambered rectangular	3.0	650					
	2.8		660	152	20	pushed	middle
	2.8		660	127	45	pushed	middle
	2.8		660	177	60	rode over	toe
	2.8		660	137	45	pushed	toe
	2.8		660	304	20	dug out	middle
	2.8		660	152	20	rode over	toe
	2.8		660	203	20	dug out	middle
	2.8		660	152	45	rode over	toe
Vee	3.0	790					
	2.9		812	223	30	rode over	middle
	2.9		812	254	30	rode over	middle
	2.9		812	228	20	rode over	toe
	2.9		812	279	45	rode over	toe
	2.9		812	208	30	rode over	middle
	2.9		812	330	20	pushed	middle
	2.9		812	203	25	rode over	toe
	2.9		914	304	20	dug out	toe
	2.9		914	152	20	rode over	toe
	2.9		914	304	20	rode over	middle
	2.9		914	254	20	dug out	toe
	2.9		914	304	25	pushed	middle

Trawls over rough ground

Video tape recordings were made of both the 200 hp Marine Laboratory 4-panel trawl and the 150-500 hp Boris 'Mystic' trawl towing from smooth sand, through rough ground and back on to smooth sand. Both trawls were fitted with a similar ground gear. All four observers remarked on the noise generated by the boards and ground gear, particularly the steel bumper bobbin and ground chains, as they struck and slid over the hard ground; the noise was heard by the divers well before the gear came into view. From both the direct visual observations and the later study of the video tapes it was seen that the ground gear of both nets remained in close contact with the sea bed when towed over both smooth sand and rough ground.

The Marine Laboratory "Lossie J" 4-panel trawl showed no slackness in the side panels or belly region. Boulders up to 1 m high (Plate VI) were passed over by the ground gear and belly netting without damage, and boulders up to approximately 2 m high were seen passing between the boards clearly in the path of this net, yet the gear suffered no damage. Rocks approximately 1 m high by 1.5 m wide were seen being pushed ahead of the bobbins, with tension increases of between 200 and 250 kg, before the ground gear eventually rolled over them. The design of the "Lossie J" net keeps the belly and quarters slightly raised immediately behind the bobbin rig even in extreme conditions.

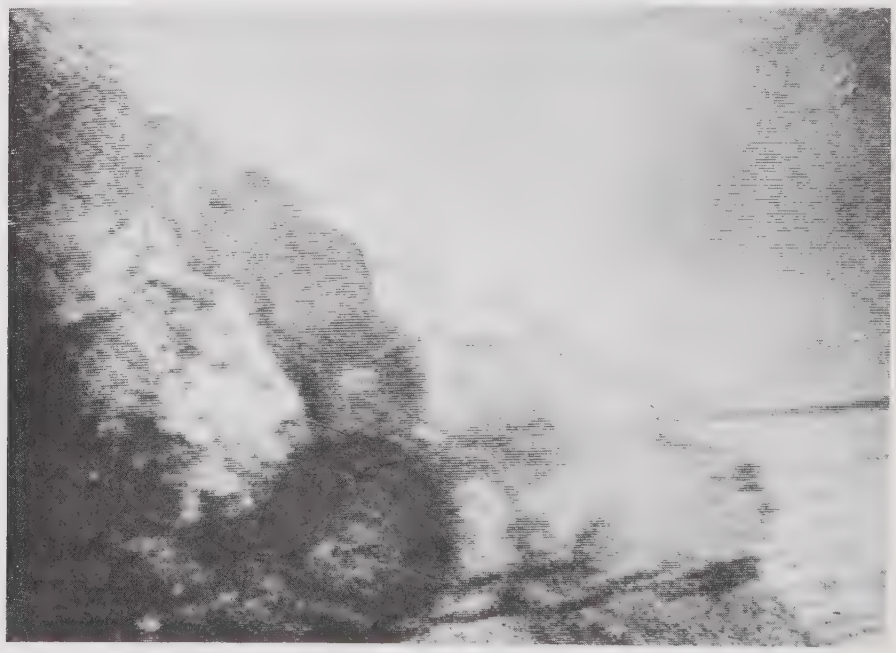


Plate VI. Ground gear of the 4-panel trawl about to clear an obstruction of approximately one meter in height.

On the hard ground, the bobbins travelling sideways at the quarters of the ground gear frequently caught on the rocks and stones and were packed hard toward the centre. The lancasters between the bosom bobbins were seen to jam on numerous occasions, and so the links between the bobbins and the fishing line rolled forward over the bobbin spacers. They pulled the fishing line with them and pulled the belly netting over the top of the bobbins (Plate VII). This jamming action characteristic of the bobbin rig used could result in damage to the belly on hard ground. Use of a lancaster roller not affected by tight packing of the bobbins would avoid this problem.

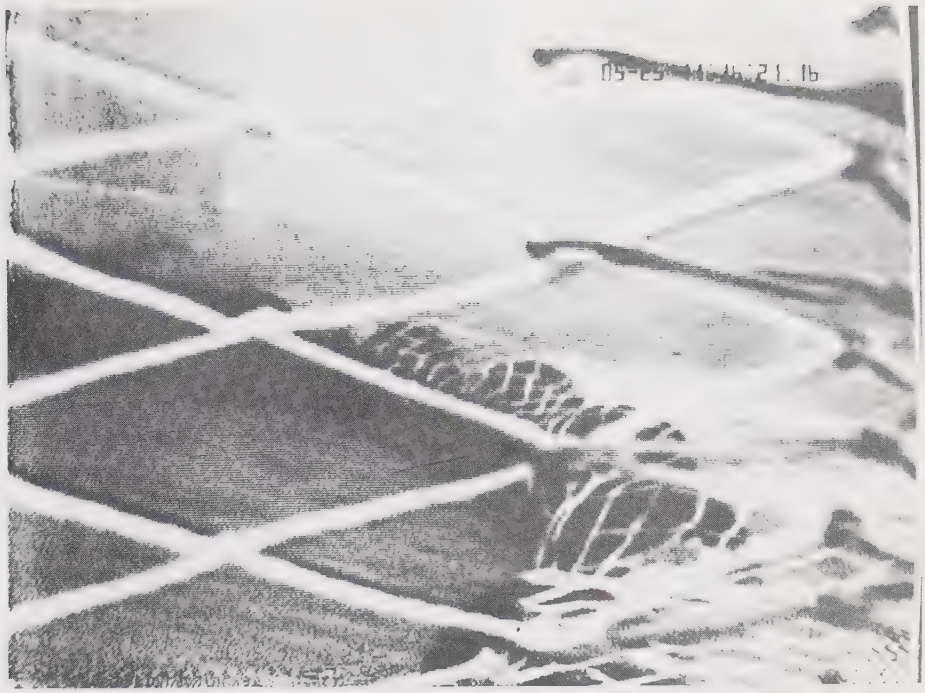


Plate VII. Belly netting of the 4-panel trawl being pulled over the bobbins. This is due to the lancaster between the bobbins jamming, resulting in the links between the bobbins and the fishing line rolling forward over the bobbin spacers. Photograph taken looking through the port side panel.

The "Boris Mystic" was rigged to fish with flying wings during these experiments in order to compare directly with the "Lossie J" 4-panel trawl. The ground gear behaved in a similar manner to that described above. The side panels were much slacker vertically, without being baggy, the meshes being strained more longitudinally than in the "Lossie J" trawl. Nevertheless, the "Mystic" had a good shape, the belly and quarter regions being flatter and wider than the "Lossie J". On encountering a rock about 1 m high, the ground gear wrapped itself around the rock and warp tension increased to 3550 kg (3½ tons) and stopped the ship. This ground gear cleared rocks 30-45 cm high and the flat area of the belly netting just cleared rocks about 60 cm high, with approximately 1.5 m of the belly sliding across the top of them. It should be noted that the maximum warp tension in the event of a severe fastener will depend upon the displacement mass of the towing vessel, towing speed and warp length. In this case, the FRV "Mara" has a displacement of 130 tons and the warp length used was 137 m (75 fm). Smaller peak loads would apply to a lighter ship working in deeper water. (MacLennan, 1978).

Discussion

When the four boards, each rigged in the same way to the Marine Laboratory 200 hp 4-panel "Lossie J" trawl, were towed over smooth sand, the average spread (distance between the two boards) of the cambered boards was 20.7 m, of the polyvalent boards 20.1 m, of the rectangular flat boards 17.5 m and of the Vee boards 17.4 m (Table II). On the hard ground, spread measurements of all four boards were reduced, with the polyvalent boards' lively behaviour reducing it on average to 15.1 m. The spread of the cambered rectangular boards on the hard ground was down 17.8 m, which was still just greater than that of either the rectangular flat or Vee boards on smooth sand. From these measurements, it appears that the cambered rectangular board gives the best spread to the gear, irrespective of type of sea bottom. The reduction in spread when passing from smooth sand to hard ground was greatest with the polyvalent boards (24.8%), whereas the least reduction (5%) was found with the rectangular flat boards. The spread of the cambered and

Vee boards was reduced by approximately 13 and 14% respectively. However, direct comparison of the spread of the doors is not possible because not all the doors are the same size, so in order to give a better indication of the relative performance of each type the spreading force per square metre was calculated (Table II).

The continuous towing warp tensions on the smooth sand for each rectangular flat board was 755 kg, for the polyvalent board 645 kg, for the cambered board 650 kg and the Vee board 790 kg (Table III). The increases in warp tension from impacts on boulders of similar height varied greatly. A standard rectangular board, for example, striking an obstruction 20 cm high, gave an increase in recorded tension of either 101 kg or 558 kg, depending on the point of impact on the board or whether the board dug the obstruction out of the sea bed or rode over it. Similarly, an obstruction of 45 cm high caused increases of 457.0 kg, 254.0 kg, 127.0 kg and 279.0 kg when struck by four different types of trawl boards. These readings depend on the point of impact of the board and the ease with which the board clears the obstruction.

The largest obstruction hit by a trawl board does not necessarily cause the largest increase in tension. For example, a rock 20 cm high, gave an increase in warp tension of 1117.0 kg because the toe of the rectangular flat board caught on and pulled the obstruction out of the sea bed, whereas a rock 1.8 m high gave an increase of 558.0 kg because the polyvalent board had the ability to rise and slide over the obstruction without much difficulty. The above results are for a warp length of 137 m (75 fm), but the rate of increase of the tension will be affected by the warp length; however, it is not so obvious how the maximum loads will be changed with longer warp length as they will be influenced also by other factors (MacLennan, 1978).

Summary

The rectangular flat board was very stable on both smooth and rough ground, cleared boulders reasonably well, but, owing to its rectangular shape and inability to rise quickly over obstructions, impacts were mostly on the leading edge. The polyvalent board cleared the rough ground with remarkable ease but its lively behaviour led to rapid decreases in spread. Nevertheless, this action could possibly help to lift the spreading wires over rough ground. The cambered rectangular board behaved similarly to the rectangular flat but its ability to spread the gear was superior to that of the other boards tested. The Vee board was stable on smooth ground and cleared the rough ground owing to its tipping action on the towing triangle.

The warp tension varied with the degree of board reaction and did not necessarily correspond to impacts with the largest obstruction, but depended on whether the obstruction was cleared, pushed, or dug out of the sea bed. The "Lossie J" trawl had the ability to pass intact over rough ground when boulders were up to 2 m high. The success of this gear is probably due to the carefully tailored belly and side panels lifting in parallel with the ground gear and helping to lift the ground gear over large boulders. The "Boris Mystic" held the ground well, but in the rig tested was found susceptible to belly damage on ground with boulders over 60 cm high; this was apparently due to the absence of upward lift from the slacker belly and side panels. Some belly damage could result in both gears from the jamming of lancaster links rolling the fishing line and belly on top of the bobbin rig, a problem increased by the tighter packing of the bobbins on hard ground.

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